Assessment of Ge-doped optical fibres as a TSL-mode detector

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ABSTRACT

This study analyses the thermally stimulated luminescence (TSL) or thermoluminescence glow curve between 300 and 773 K of germanium-doped silica optical fibre and finds a main glow peak at around 500 K with a characteristic spectral emission centred at 400 nm. Both features are particularly suitable for dosimetry.
Thus, an investigation by the TSL technique of some first clinically relevant features of a TSL sensor like the dose- and dose rate-responses is obtained. The presented studies show that germanium doped silica fibres have potential dosimetric properties and should be excellent TSL-mode detectors in instances of radiotherapy (clinical dosimetry) and *in-vivo* radiation dosimetry as well in the field of nuclear facilities.

PACS Keywords: dosimetry, radiation, silica, thermoluminescence, optical fibres

1 INTRODUCTION

In view of their high TSL sensitivity, storage stability and reliability, the outstanding advantages presented by Ge-doped optical fibres are interesting for application in ionising radiation dosimetry and have to be explored.

With the achievement of the modified chemical vapour deposition (MCVD) process, reproducible and large-scale production, high quality optical fibres are now available at moderate cost [1]. In addition, optical fibres are chemically inert, physically robust and biocompatible and their re-use and sterilisation are obtained by simple heating.

Classical dosimeters (TLD) use the property of thermoluminescence signal relative, for practical reasons; to deep trap levels and which the concentration increases with the radiation-absorbed dose. In this technique, the deep level acts as "a memory cell" of the ionising radiation doses. The properties of the deep level in the TSL process and its concentration are the critical parameters that control the behaviour of the dosimeter.

The control of the deep level within the silica band gap, by Ge impurities, might lead to a new kind of adequate TSL-mode detectors with probably some better properties than the two commercially available TLDs which have some detrimental effects like a fastidious use protocol (TLD100) or the sensitivity to ambient light (TLD500).

2 EXPERIMENTAL SETUP

The studied fibre presented here is produced by iXFiber SAS from a preform made by MCVD process. The drawing conditions of the 125 μm diameter obtained fibre are described elsewhere [2]. Germanium doping levels are designed to follow a two-step distribution.

Because of the heating, TSL analysis requires the polymer coating removal on 5 m fibre. The obtained silica material is cleaned, cut in stalks of some millimetres in length and then put on a 10 mm diameter aluminium cupel.

Irradiations were achieved at room temperature (RT) by means of an X-ray tube (Cu target, 45 kV) at different dose rates. One min after the end of irradiation, thermoluminescence readout was carried out from RT up to 750 K with a linear heating rate of 1 K/s and the signal was recorded by means of a S13 response photomultiplier (250 – 600 nm).

An optical multichannel analyser (OMA) was used to detect the spectral distribution of the TSL peak. The analyser consists of an optical fibre (fused silica) and a Chromex 250 IS spectrograph equipped with a CCD matrix (Princeton Instruments), the spectral response of the system is within the range 200-1100 nm.

3 RESULTS AND DISCUSSION

3.1 Trapping and luminescence parameters

Among various studied optical fibres, Ge-doped one and named GeD2 is by far, the most sensitive by comparison to the undoped fibre or to those containing other impurities (Al, F, P, RE,). Besides one shoulder at around 373 K, a main glow component peaking at 500 K composes the typical TSL curve of GeD2. The shoulder at 373 K, always observed by TL in all tested silica fibres, is probably due to a common intrinsic defect in silica, acting as a shallow trap level within the band gap of the material. One focuses our study on the deeper trap level characterised by this main TSL peak at 500 K and which is more convenient for dosimetric criteria. Trapping parameters associated to this peak are a mean activation energy E ≈ 1,46 eV and a frequency factor of $1{,}3 \times 10^{12}\ s^{-1}$.

Fig. 1 shows the spectral distribution of the main peak at 500 K. It consists of a blue-violet broadband luminescence (FWHM=0,4 eV) centred at 400 nm (3,1 eV). This well known emission is ascribed to the luminescence of the two-fold Ge centre (=Ge:) [3,4]. D. Griscom has already identified this centre as a trapped-electron one [5]. Indeed, the luminescence of this main peak might be described as a result of recombination on GeODC centres of holes, released at 500 K during TSL process.

Furthermore, whatever the temperature is (strip on the figure), one can see on Fig. 1 that there is only the emission at 400 nm. This implies that the shoulder at 373 K can also be ascribed as a detrapping of holes.

TSL results led us conclude on the "hole" nature of the trap defects characterised by the peaks at 373 and 500 K but their origin still remains unknown.

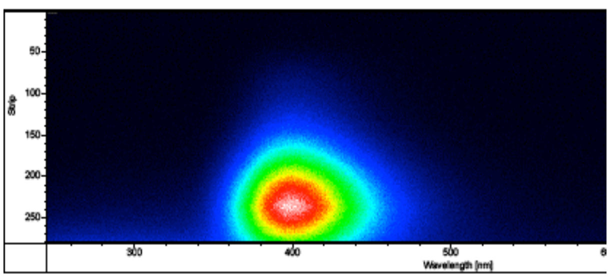

Fig. 1. Image of the dosimetric peak emission observed on GeD2 optical fibre after X-ray irradiation at RT.

3.2 Dosimetric characteristics of GeD2 fibre

GeD2 fibre shows high TSL response sensitivity of the main peak, which is ideally located in temperature, so avoiding the disturbance of the black body radiation. The luminescence emission of this peak is centred at 400 nm, that is to say in the middle of the spectral band width of all UV-Vis PM tubes used in TSL dosimetry. TSL sensitivity, peak position and spectral response constitute the first main properties of the TSL-mode detector for which GeD2 optical fibre seems to be a potential candidate for some basic dosimetry tests.

The first test was that of TSL response repeatability after five successive readout cycles on a same fibre. The estimated repeatability is within the experimental error.

The second set of tests concerns the TSL response as a function of both the dose and the dose rate of radiation. Results for two different dose rates (60 and 490 rad/s) are shown on Fig. 2. One can note that for both dose rates, the TSL response shows a quiet linear behaviour (R^2=0,998) within a wide dose range. One can also note that no obvious effect of the dose rate on the TSL response of GeD2 is observed. However, although different, these rates remain of the same magnitude.

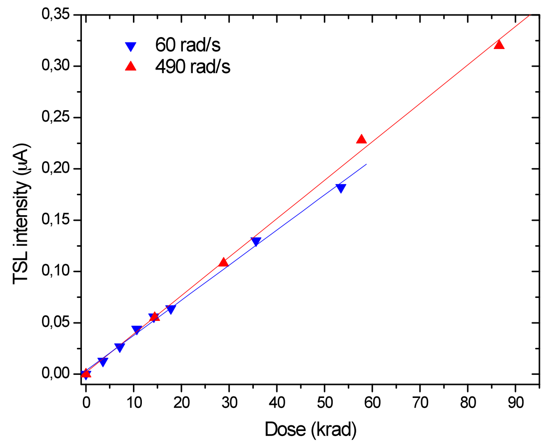

Fig. 2. TSL response of the dosimetric peak as a function of the X-ray dose.

Other dosimetric features of GeD2 optical fibre as well as a comparative study with a widely used commercial TLD are in progress.

4 CONCLUSION

These preliminary results show that GeD2 optical fibre appears to meet the various required criteria for TSL dosimetry.

The combination of a good linearity of response over a wide range of doses (up to 90 krad), a no dependence of the dose rate and are-use without any tedious treatment, make GeD2 optical fibre, a potential TSL-mode detector.

It should also be emphasised that the small size of Ge doped silica fibres together with their biocompatibility, physical robustness and chemical inertness, make these fibres well suitable for patient dosimetry.

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